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Sitting to standing postural changes: Energy expenditure and a possible mechanism to alleviate sedentary behavior

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Background: Sedentary lifestyles have recently been identified as potential mechanisms for obesity and associated metabolic diseases linked to ill health. The purpose of this study was to investigate the effects of standing and sitting-standing positional changes on energy cost and consequently interrupting sedentary sitting time while working. Methods: 26 healthy male volunteers performed normal typing and editing work for 100 minutes under three conditions. The conditions included; sustained sitting, sustained standing and sitting-standing alternation every 20min using a sit-stand desk. Respiratory parameters measured included minute ventilation (VE), oxygen consumption (VO_2) and energy expenditure (EE). Measurements were recorded using a calibrated Cosmed K4b^2 portable gas analysis system. Results: The mean value for VE in the standing position (VE=13.33±0.71) was the highest, followed by sitting-standing alternation (VE=12.04±0.62). Both were significantly different from sitting (VE=10.59±0.69). The maximum VE and EE for standing (VE=14.81±0.43, EE=1.84±0.10) and sitting-standing alternation (VE=14.80±0.40, EE=1.93±0.08) were significantly higher than that of sitting (VE=12.15±0.42, EE=1.67±0.07). No significant differences were observed in the mean VO_2 among the three conditions. However, the maximum VO_2 for both standing ($VO_{2=}$5.40±0.20) and sitting-standing alternation ($VO_{2=}$5.14±0.17) showed to be significantly higher than sitting ($VO_{2=}$4.50±0.18). There were no significant differences observed in the mean EE levels between sitting (EE=1.43±0.07) and sitting-standing alternation (EE=1.55±0.08). However, the mean EE while standing (EE=1.62±0.09) increased significantly compared with sitting. Conclusions: The findings of this study indicate that sitting-standing alternations may be implemented as an effective intervention to interrupt prolonged sitting while working.

Keywords: Sedentary behavior, Sitting-standing alternation, Energy expenditure, Health benefits, Expenditure

Introduction

Sedentary behavior has long been associated with increased ill health (11,17). Evidence suggests that there is a positive relationship between sitting time and risk of type II diabetes, (25, 30) and associated pathologies (13, 23, 24). In addition, low energy expenditure observed during a seated posture (15) is considered an important contributory factor in the increased prevalence of obesity (18, 20, 28).

Previous studies have suggested that strategies the promote activity as opposed to sedentary behavior may improve health outcomes (6). Research by (2) provided guidelines for employers to promote to avoidance of prolonged periods of sedentary work, suggesting that seated-based work should be regularly alternated with the goal of accumulating 2 hours of standing per day. Potential mechanism for promoting health by reducing sedentary time may be associated with increased oxidative metabolism when using treadmill and sit-stand workstations during walking and standing. In a work-based environment, energy expenditure while sitting is reported to be 45-76 kcal/h, which increases to 88 kcal/h while standing and 148-191 kcal/h while walking (20, 1, 9). More recently, Carter et al (5) reported that treadmill walking led to a higher total energy consumption and heart rate compared with sitting and standing. However, the relatively high cost of a treadmill desk and related equipment is likely to limit practical applications (4). In addition, high intensity activity (moderate-to-vigorous intensity) such as jogging on a treadmill may potentially impair work productivity and could be dangerous (21). Also, both methods would seem to be impractical in a workplace environment.

Alternatively, standing has been considered an effective intervention used to avoid the negative effects of sedentary time without affecting work productivity (7). Buckley et al. (3) noted that along with attenuated postprandial blood glucose, energy expenditure during an afternoon standing session while working was 0.83 Kcals/min higher than performing the same task while sitting. However, previous research has demonstrated that prolonged standing may lead to lower leg swelling, knee discomfort and venous pooling (8). Lower back fatigue and pain have also been frequently reported as a consequence of prolonged standing (14, 22). Júdice et al. (19) compared the metabolic/energy cost between sitting, standing and sitting-standing transition. They observed that sitting-standing transition (1set/min) and sustained standing had a metabolic cost of 0.32 Kcal/min and 0.07 Kcal/min higher than sitting, respectively. However, a limitation of the study was that it only measured metabolic cost for a short time period (10mins).

Because it is not feasible to repeat one set of sitting-standing transition per minute during an 8-hour work period, the effects of longer durations of standing or sitting-standing alternations on energy cost in attenuating sedentary behavior remains unclear. Therefore, the purpose of this study was to explore the respiratory differences in minute ventilation (VE), relative oxygen consumption (VO_2), energy expenditure (EE), and respiratory exchange ratio (RER) between sitting, standing and sitting-standing postural changes every 20mins during 100-minutes of actual working time. It was hypothesized that standing and sitting-standing alternation would increase energy cost compared with sustained sitting.

Materials and Methods

Study design

26 healthy males volunteered to participate in this experiment. The average age of participants was 23.20±1.83 years, the average stature was 177.65±4.47 cm, the average mass was 69.5±3.68 kg, and the average Body Mass Index (BMI) was 21.99±0.89 kg/m^2. Participants with smoking history, cardiovascular disease, endocrine and metabolic disorders were excluded from the study following medical screening. This study was approved by the Human Ethics Committee of Ningbo University (Reference Number: ARGH20160621). All subjects were informed about the consent for inclusion in the study, the goal and funding organization of the study.

Equipment

A calibrated K4b^2 portable gas analysis system (COSMED, Rome, Italy) was used to measure respiratory parameters. The K4b^2 system has been proven as a valid and reliable device for measuring oxygen consumption (10). It is a portable telemetric analysis system measuring VE (minute ventilation), F_EO_2 (fractional concentrations of expired oxygen) and F_ECO_2 (carbon dioxide) during breathing, VO_2 (oxygen consumption) and VCO_2 (the volume of carbon dioxide produced). Prior to data collection, the system was calibrated using the unit's microprocessor in conjunction with the Haldane transformation algorithm. A sit-stand desk (Loctek, China), the height of which was adjusted to the height of participants via an electric system, was used in the experiment (Fig 1).

Study design and data collection

Environmental temperature in the laboratory was kept controlled and constant between 21-24 °C. Participants were required to avoid strenuous exercise 24 hours prior to testing. The participants were also told to avoid using caffeine or other stimulants 24 hours prior to the test, and to avoid food consumption 2 hours before the commencement of the experiment. Each subject was advised to adjust the desk height while sitting as well as standing. This facilitated a comfortable and erect posture under all conditions. Additionally, all subjects were given familiarization periods to ensure that they could work comfortably wearing the K4b^2 portable gas analysis system face mask. For each subject, tests were implemented under three conditions within three days. During measurement, all subjects were required to perform normal text editing tasks or video watching activities lasting 100min at the same time period of each day. This avoided the effects of diurnal variation on data collection between the three conditions. Subjects were randomly assigned to each condition. Talking was not allowed during the data collection period. The different testing conditions are outlined below;

Condition 1 (Day 1): On the first day, tests were performed under sitting conditions from 9: 30 am to 11: 10 am. The average height of desk was 86±4.92 cm.

Condition 2 (Day 2): On the second day, tests were performed under standing conditions from 9: 30 am to 11: 10 am. The average height of desk was 115±5.01 cm.

Condition 3 (Day 3): On the third day, tests were performed under sitting-standing conditions from 9: 30 am to 11: 10 am. Posture alteration occurred every 20 min with a starting posture of standing (session 1: standing from 9: 30 am to 9: 50 am; session 2: sitting from 9: 50 am to 10: 10 am; session 3: standing from 10: 10 am to 10: 30 am; session 4: sitting from 10:30 am to 10: 50 am; session 5: standing from 10: 50 am to 11: 10 am). The average height of desk while standing and sitting was 115±5.01 cm and 86±4.92 cm, respectively.

Fig 1. *Data collection while standing (A)/sitting (B) with K4b^2 portable gas analysis system before* *sit-stand desk.*

Statistical Analysis

Respiratory parameters for minute ventilation (VE), oxygen consumption (VO_2), energy expenditure (EE), and respiratory exchange ratio (RER) during the 100-minute test were collected and selected for analysis. Descriptive subject characteristics were presented as means ± SD. All analyses were conducted using SPSS for Windows, version 19.0 (SPSS Inc., Chicago, IL, USA). An analysis of variance (ANOVA) was used to examine differences in VE, VO_2, and EE between the different postures of standing, sitting and sitting-standing. Significance level was set at $p<0.05$. Where significant differences were observed the Bonferroni post hoc test was conducted.

Results

Fig. 2 shows values for oxygen consumption (VO_2), minute ventilation (VE), and energy expenditure (EE) between sitting, standing and sitting-standing during 100-minute testing. Although the mean VO_2 for standing and sitting-standing alternation was 16.83 % and 14.36 % respectively higher than sitting, there were no significant differences among three conditions (Table 1). The maximum VO_2 for both standing and sitting-standing alternation showed to be significantly higher than sitting (Table 1). As shown in Fig. 2(a), the curve for VO_2 exhibits a rapid increase in the first 10 minutes for sitting and 20 minutes for standing and sitting-standing posture change. The curve for VO_2 in the standing condition enters into a relatively steady phase with a slight increase. During sitting, it shows a second peak approximately at the 50 minute testing stage. Different from the curve recorded for sitting and standing, the curve for sitting-standing posture change seems to be more irregular and fluctuating.

As shown in Fig 2(b), the mean VE for standing is the highest during the entire 100-minute testing period, followed by the sitting-standing postural change with sitting recording the lowest value. The curves of VE of standing and sitting show a constant trend compared with sitting-standing postural change. Similar to the curve observed for VO2, the curve for VE recorded for sitting-standing postural change also seems to be irregular and fluctuating. Changes for mean EE are comparable with VE corresponding to each condition (Fig 2(c)). The maximum VE and EE for standing and sitting-standing alternation were significantly higher than that of sitting (Table 1). Significant difference was also observed in the mean EE between sitting and standing (Table 1). The differences were not significant when comparisons were made between sitting and sitting-standing postural changes (Table 1).

Fig 2. Comparison of VO_2 (a), VE (b) and EE (c) between sitting (solid line), standing (dashed line) and sitting-standing alternation (dot line) while 100-minute test.

Table 1. Characteristics of VO_2, VE, EE and RER **during 100-minute sitting (Sit); standing (Stand) and sitting-standing alternation (Sit-stand) (mean ± SD).**

		Sit	Stand	Sit-stand
	Mean	4.04±0.38	4.72±0.42	4.62±0.49
VO_2(ml/min/kg)	Increase %	-	16.83±3.46	14.36±2.72
	Max	4.50±0.18	5.40±0.20 **	5.14±0.17 #
	Mean	10.59±0.69	13.33±0.71 **	12.04±0.62 #
VE(min^{-1})	Increase %	-	25.87±5.83	13.69±2.02
	Max	12.15±0.42	14.81±0.43 **	14.80±0.40 ##
	Mean	1.43±0.07	1.62±0.09 *	1.55±0.08
EE(Kcal/min)	Increase %	-	13.28±1.88	8.39±0.94
	Max	1.67±0.07	1.84±0.10 **	1.93±0.08 #
RER	Mean	0.83±0.08	0.85±0.09	0.87±0.05

Note: Increase % refers to percentage increases of the mean VO_2, VE and EE while standing and sitting-standing alternation compared with sitting. - refers to none value. * $P<0.05$, Sit vs Stand; # $P<0.05$, Sit vs Stand-sit; ** $P<0.01$, Sit vs Stand; ## $P<0.01$, Sit vs Stand-sit.

Fig. 3 shows the segmented energy expenditure every 20mins. As listed in Table 2, the total EE for standing was higher than sitting, and statistical analysis showed significant differences during all segmented periods. Differences in the total EE between sitting-standing postural change and sitting was not noticeable compared with sitting except for the first period (from 0 to 20 min) ($P<0.041$). Results of the mean EE per minute remained consistent with the total EE. With regard to the increase rate of EE per minute, it showed negative values during sitting periods of sitting-standing postural changes (the second and fourth periods) with downward trend. EE also showed a raising/upward trend during standing periods (the first, third and fifth periods) (Fig. 3).

Fig 3. *Segmented energy expenditure. From 0 to 20 minute (A), 20 to 40 minute (B), 40 to 60 minute (C), 60 to 80 minute (D), 80 to 100 minute (E) while sitting (solid line), standing (dashed line) and sitting-standing alternation (dot line).*

Table 2. Comparison of energy expenditure during different phases.

Phases		Sit	Stand	Sit-stand
0-20 min	V(Kcal/min)	$(13.26\pm1.49)10^{-3}$*	$(20.67\pm3.01)10^{-3}$*	$(17.5\pm1.86)10^{-3}$*
	Mean (Kcal/min)	1.260±0.089	1.464±0.133*	1.467±0.101#
	Total (Kcal)	25.191±2.37	29.292±2.61*	29.523±2.44#
20-40 min	V(Kcal/min)	$(5.28\pm0.76)10^{-3}$*	$(-0.22\pm0.06)10^{-3}$*	$(-5.26\pm0.69)10^{-3}$*
	Mean (Kcal/min)	1.350±0.037	1.570±0.011*	1.499±0.041
	Total (Kcal)	27.007±2.19	31.405±2.51*	29.971±2.22
40-60 min	V (Kcal/min)	$(2.45\pm0.31)10^{-3}$*	$(1.59\pm0.27)10^{-3}$*	$(9.89\pm0.92)10^{-3}$*
	Mean (Kcal/min)	1.479±0.015	1.609±0.007*	1.577±0.066
	Total (Kcal)	29.589±2.10	32.181±2.81*	31.537±2.38
60-80 min	V (Kcal/min)	$(-0.88\pm0.01)10^{-3}$*	$(6.97\pm0.85)10^{-3}$*	$(-8.23\pm0.9)10^{-3}$*
	Mean (Kcal/min)	1.481±0.006	1.699±0.048*	1.589±0.058
	Total (Kcal)	29.614±2.42	33.975±3.15*	31.771±2.75
80-100 min	V (Kcal/min)	$(10.01\pm1.58)10^{-3}$*	$(3.73\pm0.30)10^{-3}$*	$(21.7\pm2.65)10^{-3}$*
	Mean (Kcal/min)	1.558±0.070	1.782±0.023*	1.603±0.121
	Total (Kcal)	31.160±2.55	35.639±3.08*	32.056±2.75

Note: V (Kcal/min) indicates the increase of energy expenditure per minute. * $P<0.05$, Sit vs Stand; # $P<0.05$, Sit vs

Stand-sit.

Discussion

Office workers spend hours sitting at desks without ambulation; as a result, intermittent standing during office work provides a simple and feasible intervention to reduce the negative effects of sedentary time by increasing energy expenditure. This study provided evidence how sitting-standing postural changes affect sedentary behavior in terms of energy cost.

Different from moderate exercise of sitting-standing transition with a frequency of one repetition per minute reported by Júdice et al. (19), this study tested energy cost under minimal intensity physical activity of sitting-standing alternation every 20min. Additionally, longer duration of 100-minute testing is more realistic for simulating sedentary behavior than shorter periods of 10 minutes (19). The mean VE (minute ventilation) while standing and sitting-standing alternation increased significantly ($p<0.05$) compared with sitting. In contrast to expected outcomes, statistical significance in the mean EE was only observed between sitting and standing, while there were no differences observed between the sitting and sitting-standing condition. Thorp et al. (27) investigated energy expenditure while sitting and alternating between standing and seated work posture every 30min among a group of obese individuals. Findings from the study indicated that intermittent standing at work can modestly increase (13%) daily workplace energy expenditure compared to seated work. Moreover, it is important to highlight that if the standing portion of the sit-stand cycle is too long, it may lead to musculoskeletal discomfort, swelling and fatigue in lower limbs, low back pain and chronic venous insufficiency (8, 26). Research by Hasegawa et al. (16) supported the notion that change of posture while sitting helps to alleviate the feeling of fatigue during short-term light repetitive tasks. There was a gradual decline in EE during the second and fourth periods during the sitting-standing alternating condition. In contrast, the curves generated for the sitting and standing condition appear to be flat with an obvious increase noted during the fourth period. It is sensible to suggest that sitting periods while sitting-standing alternation could be classified as recovery phases, which may help to reduce any fatigue caused by prolonged periods of standing. With respect to work productivity, Ebara et al. (12) stated that there was a tendency to be more productive when a combination of 10-minute sitting and 5-minute standing compared with sustained sitting within 150 minutes was observed. In spite of the decline in EE during the second and fourth periods in this study, the mean EE of sitting-standing alternation was 8.39 % higher than sitting during the entire 100-minute testing period. It seems feasible that sitting-standing alternation with minimal intensity may lower the health risks associated with sedentary behavior without affecting productivity in the work place.

It is also possible to suggest that the responses observed by influencing sedentary time of 100-minute durations with standing and sitting-standing alternations every 20min have the potential to produce longer term health benefits if the routines were performed over an extended period. Over an eight-hour working day, additional energy expenditure values of 95.67 Kcal and 59.02 Kcal would be expended when performing sustained standing and sitting-standing alternations respectively compared with only sitting for the same period. However, previous research has suggested that prolonged standing of less than1 hour and a total duration of less than 4 hours per day is considered to be safe and practical (29).

There are several limitations of this study. Firstly, it is difficult to include all related factors, such as work stress, meetings, and associated work like duties untertaken in a real work environment. Secondly, this study only recruited male subjects who were under 25 years old; therefore, potential gender and age differences may contribute to the measurements observed in this study. Further research is needed to explore the contribution of these variables in the assessment of EE in the workplace.

Thirdly, in addition to the measurement of energy expenditure, further studies could focus on physiological indexes such as blood pressure, body mass index, waist circumference, blood biochemistry including cholesterol, and postprandial glucose responses. These further measures would provide potential underlying causality detail between improving health outcomes and interrupting sedentary time with the intervention of sitting-standing alternations.

Conclusions

This study confirmed that light intensity physical activity of sustained standing and sitting-standing alternations increase the energy cost compared with sustained sitting. There were no significant differences in the mean oxygen consumption among three conditions. The mean minute ventilation while standing was the highest, followed by the sitting-standing alternation. The mean EE while standing was significantly higher than sitting. In addition, the sitting-standing alternation was 8.39% higher than sitting without significance. This indicates that by moderately extending the standing portion of the sitting-standing condition would result in increasing EE compared with sustained sitting alone. However, when consideration is given to the hazards associated with prolonged standing, although beneficial in increasing EE it is suggested that periods of standing should be interspersed with periods of sitting to reduce fatigue.

Competing interests

The authors declare that they have no competing interests.

Acknowledgements

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A B

Fig 1. *Data collection while standing (A)/sitting (B) with K4b*^{2} *portable gas analysis system before sit-stand desk.*

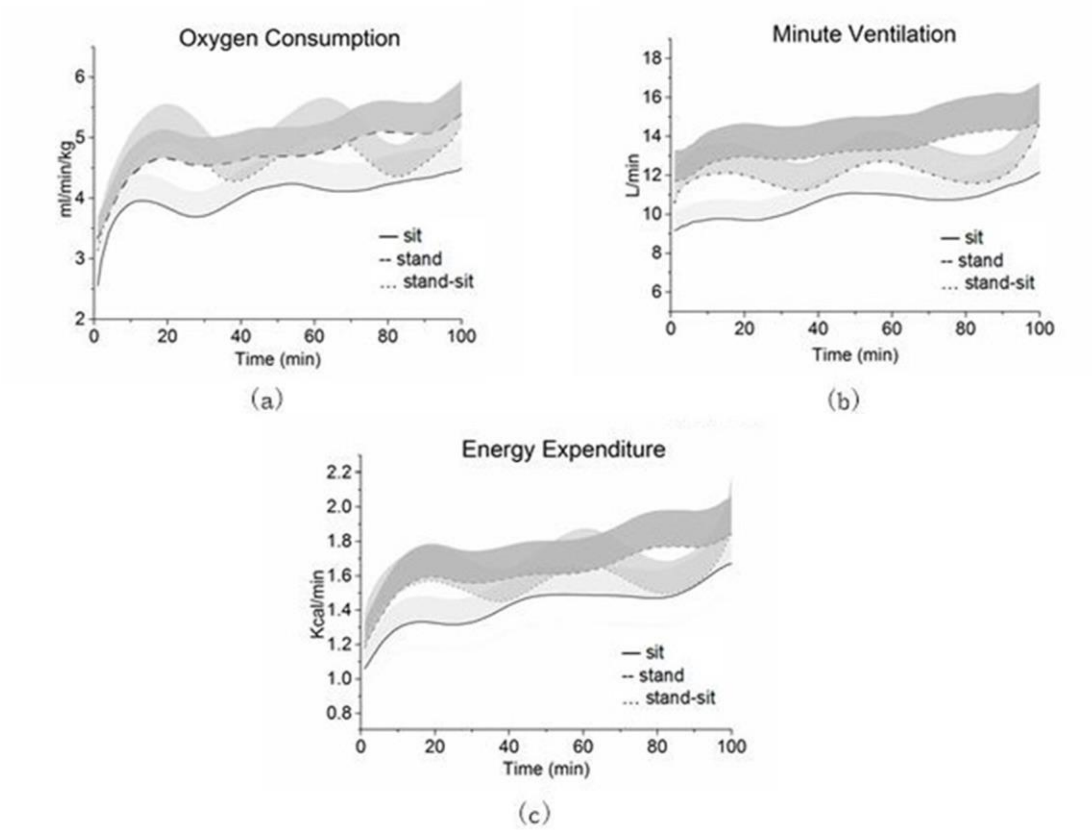

Fig 2. *Comparison of VO_2 (a), VE (b) and EE (c) between sitting (solid line), standing (dashed line) and sitting-standing alternation (dot line) while 100-minute test.*

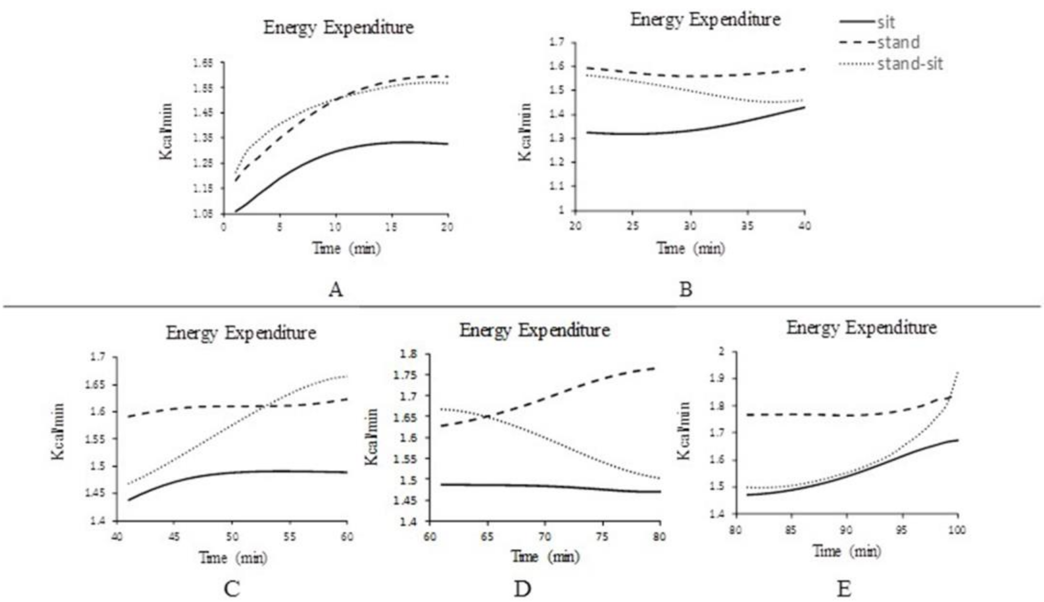

Fig 3. *Segmented energy expenditure. From 0 to 20 minute (A), 20 to 40 minute (B), 40 to 60 minute (C), 60 to 80 minute (D), 80 to 100 minute (E) while sitting (solid line), standing (dashed line) and sitting-standing alternation (dot line).*